Passage V

A *cathode-ray tube* (CRT) is a sealed, evacuated glass tube with a filament at one end and a fluorescent screen at the other end (see Figure 1).

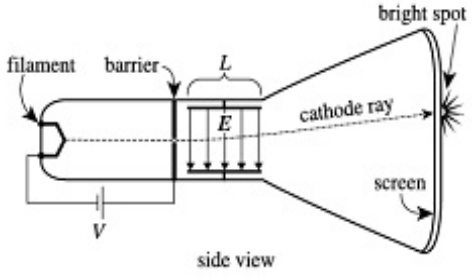

Figure 1

Figure 1 adapted from David Halliday, Robert Resnick, and Jearl Walker, *Fundamentals of Physics*, 9th ed. ©2011 John Wiley & Sons, Inc.

When heated, the filament emits cathode rays that are accelerated by an electric potential, V, toward a barrier having a pinhole. Beyond the barrier are 2 conducting plates, each of length L, that have an electric field, $\vec{E}$, between them. (The direction of $\vec{E}$ can be upward or downward; in Figure 1, it is downward.) Any rays that pass through the pinhole travel through the field and strike the screen, producing a bright spot of visible light.

A group of students performed 3 studies on various CRTs, each of which had a ruler taped to the outer surface of the screen (see Figure 2) to measure a spot's vertical location, y (in centimeters, cm).

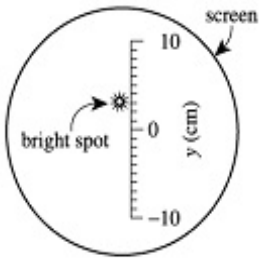

Figure 2

Study 1

The students obtained a CRT having $L = 2.5$ cm. They set V to 1.0 kilovolt (kV), varied both the direction and the magnitude (in newtons per coulomb, N/C) of $\vec{E}$, and recorded the resulting values of y (see Table 1).

Table 1

Trial	$\vec{E}$ direction*	$\vec{E}$ magnitude (N/C)	y (cm)
1	↑	1.0×10^4	−3.2
2	↑	2.0×10^4	−6.3
3	↑	3.0×10^4	−9.5
4	↓	1.0×10^4	3.2
5	↓	2.0×10^4	6.3
6	↓	3.0×10^4	9.5

*↑ = upward
↓ = downward

Study 2

Using the CRT from Study 1, the students set the magnitude of $\vec{E}$ to 1.0×10^4 N/C, varied V, and recorded the resulting values of y (see Table 2).

Table 2

Trial	V (kV)	y (cm)
7	0.5	6.3
8	1.0	3.2
9	1.5	2.1
10	2.0	1.6
11	2.5	1.3

Study 3

The students obtained various CRTs, each having a different L. For each CRT, they set V to 1.0 kV, set the magnitude of $\vec{E}$ to 1.0×10^4 N/C, and recorded the resulting value of y (see Table 3).

Table 3

Trial	L (cm)	y (cm)
12	1.5	−2.0
13	2.0	−2.6
14	2.5	−3.2
15	3.0	−3.8
16	3.5	−4.4

28. Studies 1 and 2 differed in which of the following ways? In Study 1, the students determined how the spot's location varied with:

- **F.** electric potential, whereas in Study 2, they determined how the spot's location varied with the magnitude and direction of the electric field.
- **G.** plate length, whereas in Study 2, they determined how the spot's location varied with electric potential.
- **H.** the magnitude and direction of the electric field, whereas in Study 2, they determined how the spot's location varied with electric potential.
- **J.** plate length, whereas in Study 2, they determined how the spot's location varied with the magnitude and direction of the electric field.

29. Suppose that the students had performed a trial in Study 2 in which y was 2.6 cm. The value of V in this trial would most likely have been:

- **A.** less than 1.0 kV.
- **B.** between 1.0 kV and 1.5 kV.
- **C.** between 1.5 kV and 2.0 kV.
- **D.** greater than 2.0 kV.

30. Figure 2 could serve as an illustration of the result(s) of which trial(s)?

- **F.** Trial 1 only
- **G.** Trial 8 only
- **H.** Trials 1 and 4 only
- **J.** Trials 4 and 8 only

31. Based on the results of Study 1, in which direction did $\boldsymbol{E}$ most likely point in Study 2, and in which direction did $\boldsymbol{E}$ most likely point in Study 3 ?

	Study 2	Study 3
A.	↑	↑
B.	↑	↓
C.	↓	↑
D.	↓	↓

32. Once a CRT is sealed, it cannot be reopened. However, because both V and $\boldsymbol{E}$ are controlled from the outside, a CRT can be used repeatedly under varying conditions. Based on the descriptions of Studies 1–3, what is the *minimum* number of different CRTs that the students required to complete the 3 studies?

- **F.** 1
- **G.** 5
- **H.** 11
- **J.** 16

33. Suppose that the students had performed a trial in which the cathode rays traveled all the way from the filament to the screen in a straight-line path, striking the screen at $y = 0$ cm. Based on the results of Studies 1 and 2, which of the following statements about V and the magnitude of $\boldsymbol{E}$ in this trial would have been true?

- **A.** V was zero but the magnitude of $\boldsymbol{E}$ was nonzero.
- **B.** V was nonzero but the magnitude of $\boldsymbol{E}$ was zero.
- **C.** Both V and the magnitude of $\boldsymbol{E}$ were zero.
- **D.** Both V and the magnitude of $\boldsymbol{E}$ were nonzero.

34. In a CRT, $\boldsymbol{E}$ is generated by building up equal and opposite electric charges on the 2 conducting plates. Suppose that cathode rays are negatively charged. If $\boldsymbol{E}$ is directed downward as shown in Figure 1, which conducting plate is more likely the negatively charged plate?

- **F.** The top plate, because charges of like sign are attracted to each other.
- **G.** The top plate, because charges of like sign are repelled from each other.
- **H.** The bottom plate, because charges of like sign are attracted to each other.
- **J.** The bottom plate, because charges of like sign are repelled from each other.